



Solar Photovoltaic Systems

**General Overview of Utility Interactive
PV Systems, Design
Recommendations, and Code
Compliance**

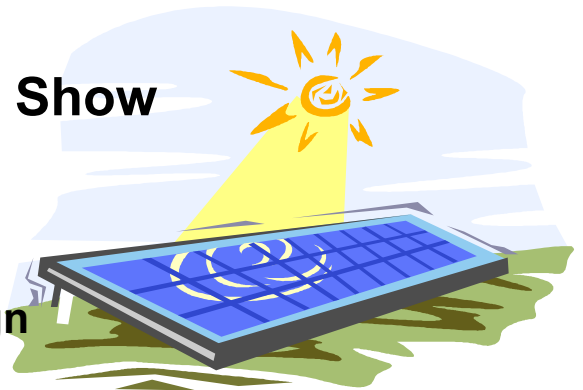
****Coral World PV System****

US Virgin Islands PV/DG Road Show

Presented by:

Onaje Jackson

Sustainable Systems and Design





Presentation Overview

- ◆ **Overview of Interactive Solar Photovoltaic Systems**
- ◆ **Overview of Codes and Standards related to PV Design and Installations**
- ◆ **Elements of A Quality PV System Design and Installation**
- ◆ **Overview of PV System Components and Functions (with reference to key elements of standards and codes)**
- ◆ **Site Review of Coral World PV System**
- ◆ **Reference resources**



Requirements for Solar Photovoltaic System Installations

◆ **Permits**

- Building permits are applied for by contractor or property owner.
- Plans examiner reviews plans, grants approvals as required.

◆ **Installation**

- System is installed by a licensed contractor (or property owner) in a code-compliant manner, in accordance with jurisdictional requirements.

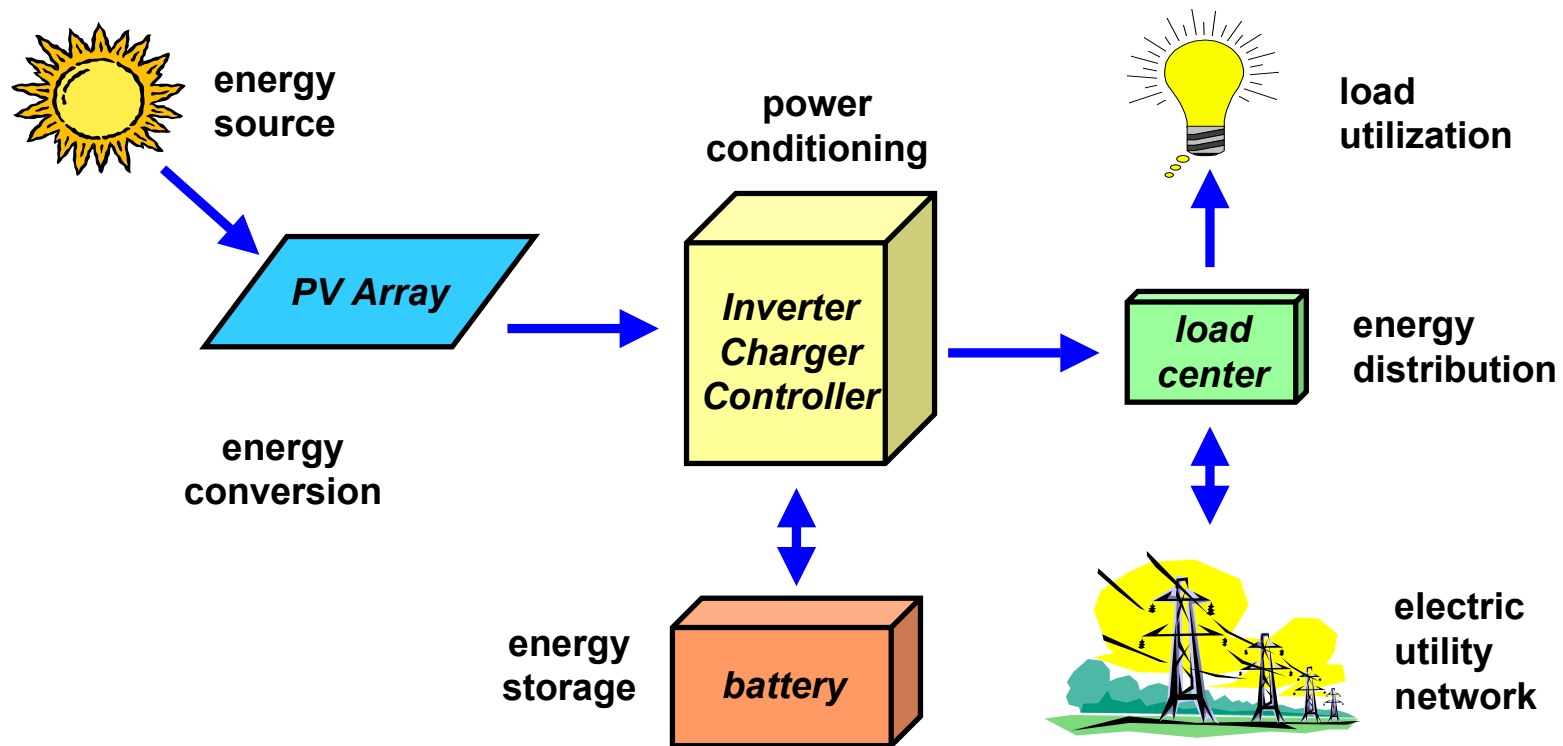
◆ **Inspections**

- Installation is inspected by the local building code official and approved.

◆ **Interconnection**

- Owner completes interconnection agreement with local utility, including requirements for system design and equipment, inspection certificates, insurance, disconnect provisions and other matters as required.

Solar Photovoltaic System: Advance Organizer





Types of Interactive Solar Photovoltaic Systems

◆ **Simple Utility-Interactive**

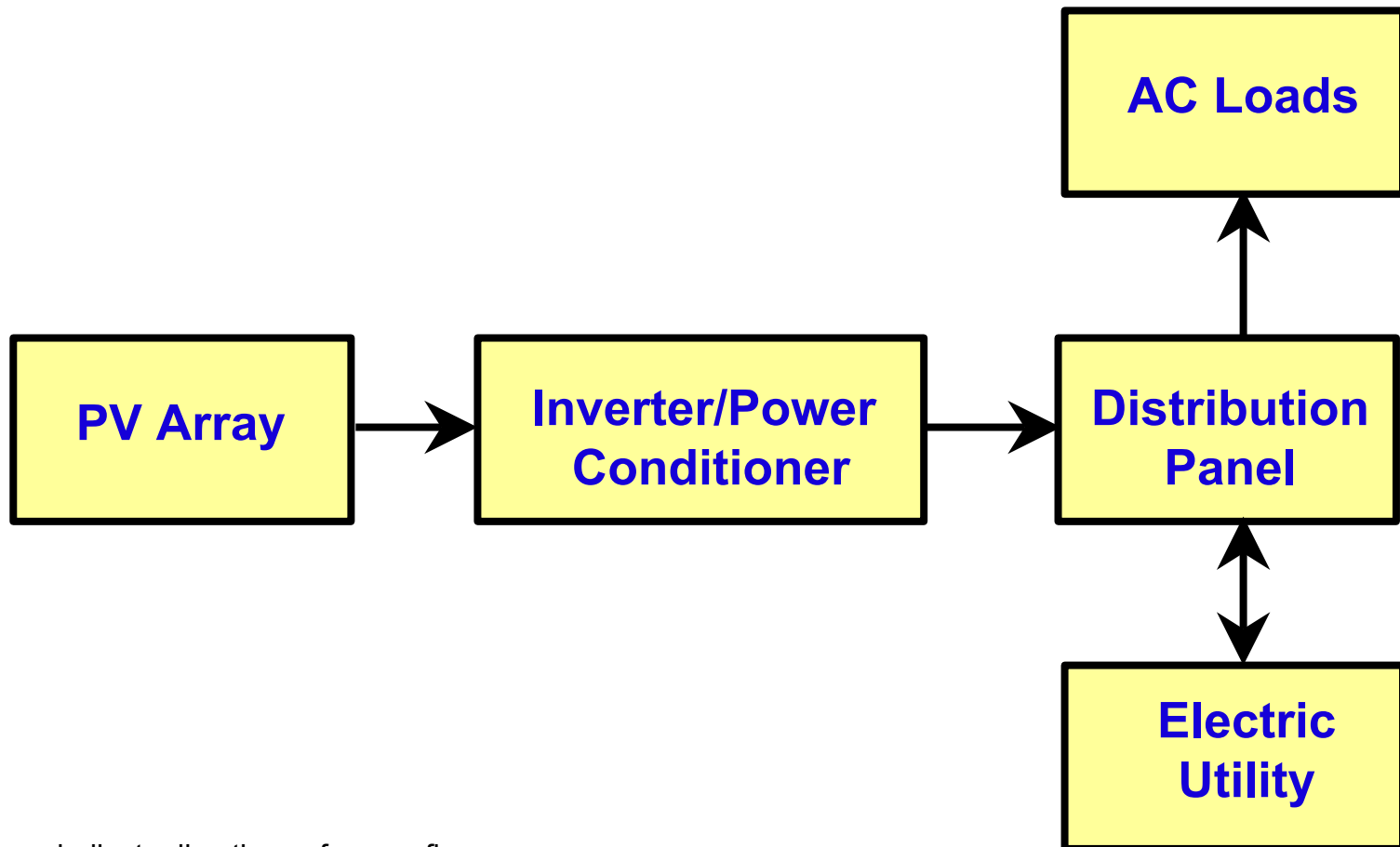
- PV system supplements on-site energy usage, electrical loads are supplied by either the PV system or utility or a combination of both, depending on the amount of PV generation and magnitude of the load.
- PV array is directly connected to the inverter input, and inverter AC output is connected to the utility grid.
- PV system operates in parallel and synchronously with the utility grid.

◆ **Utility Interactive with Battery Storage**

- Can operate either in interactive or stand-alone mode, but not simultaneously.
- PV, inverter and battery subsystems interface between the customer's main service panel and dedicated load subpanel.
- In interconnected mode, excess PV energy not required for battery charging is inverted and supplements on-site loads or is sent back to utility.
- When the grid de-energizes, inverter isolates from grid and powers load subpanel directly from batteries, similar to a UPS system.
- Bypass switch allows load subpanel to be directly powered from grid, isolating the SPS.



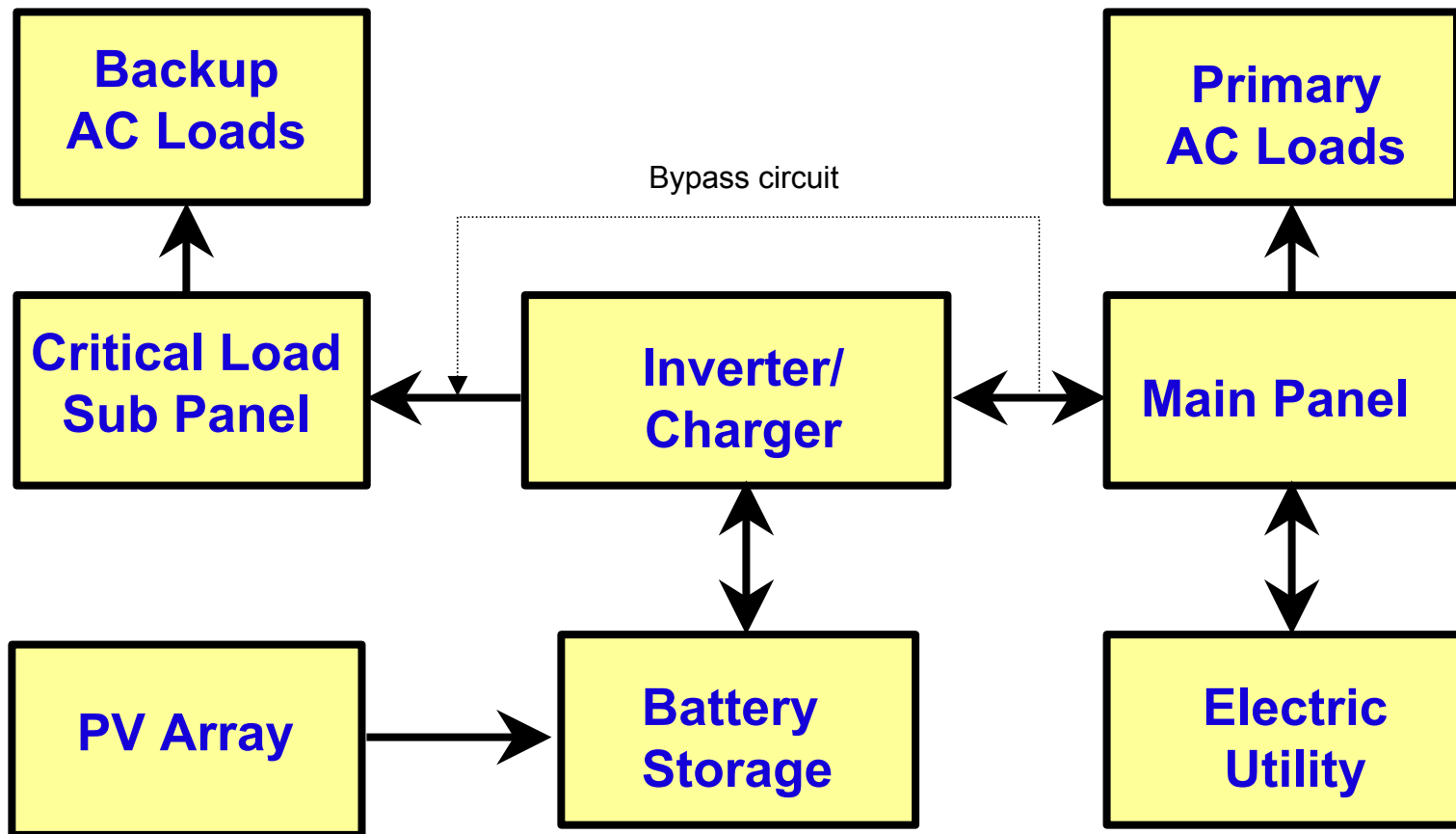
Simple Utility-Interactive PV System (no energy storage)




* Arrows indicate directions of power flows



Utility-Interactive PV System with Battery Storage



* Arrows indicate directions of power flows




Principal Standards for Solar Photovoltaic Systems and Equipment

- ◆ **IEEE 929-2000 Recommended Practice for Utility Interface of Photovoltaic (PV) Systems**
 - IEEE P1547 Draft Standard for Distributed Resources Interconnected with Electric Power Systems (will apply to a broad range of interconnected distributed generation equipment)
- ◆ **UL Standard 1741 – Inverters, Converters, and Controllers for Use in Independent Power Systems**
 - Includes requirements of IEEE 929-2000
- ◆ **UL Standard 1703 – Flat-Plate Photovoltaic Modules and Panels**
- ◆ **National Electrical Code™**
 - Article 690 Solar Photovoltaic Systems
 - Article 705 Interconnected Electric Power Production Sources
 - Requires inverter UL1741 listing identified for interactive operation
- ◆ **Local and state building codes**



PV Systems and the National Electrical Code[©]

- ◆ **Article 690** addresses safety standards for the installation of PV systems.
- ◆ Many other articles may also apply to PV installations:
 - Article 110: Requirements for Electrical Installations
 - Article 230: Disconnect Means
 - Article 240: Overcurrent Protection
 - Article 250: Grounding
 - Article 300: Wiring Methods
 - Article 480: Storage Batteries
 - Article 685: Integrated Electrical Systems
 - Article 705: Interconnected Electric Power Production Sources
 - Article 720: Circuits and Equipment Operating at Less than 50 Volts



Elements of a Quality and Code-Compliant PV System Installation

- ◆ **System employs a well-engineered design and quality components;**
- ◆ **System and equipment are sized in consultation with owner/operators to meet both short and long-term loads. Meets performance requirements based on planned facility uses;**
- ◆ **Facility managers take “hands-on” role in system design and installation.**
- ◆ **System uses listed, approved and appropriately rated equipment, and sunlight and weather resistant materials for outdoor application;**
- ◆ **PV array is mounted in an accessible, unshaded location with proper solar orientation, and uses roof penetrations and weather sealing methods consistent with accepted roofing industry standards;**
- ◆ **All equipment is properly labeled and safety hazards identified;**
- ◆ **Installation complies with all applicable building and electrical codes and accepted utility interconnection practice;**
- ◆ **System is inspected and approved by code officials.**



PV System Code Compliance: Common Problem Areas

- ◆ Insecure structural attachment of PV arrays to rooftops and other structures (e.g., attachment of roof mounts directly to roof decking)
- ◆ Inadequate weather sealing for roof penetrations
- ◆ Unsafe wiring methods, insufficient conductor ampacity and insulation type
- ◆ Lack of or improper placement or ratings of overcurrent protection and disconnect devices
- ◆ Unsafe installation, improper use and maintenance for batteries
- ◆ Use of unlisted equipment or improper application of listed equipment
- ◆ Lack of or improper system grounding
- ◆ Lack of or inadequate labeling on major system components and disconnect devices
- ◆ Lack of or inadequate documentation on system design, and operating and maintenance requirements



Solar Photovoltaic System Components

◆ **PV Array**

- An electrical assembly of photovoltaic modules that convert sunlight to DC electricity.

◆ **Inverter**

- A device that converts DC power from batteries or PV arrays into utility-grade AC power.

◆ **Energy Storage**

- Electrical or other storage devices sometimes used to store energy produced by PV arrays for later consumption.

◆ **System Charge Control**

- A device used to protect batteries from overcharge and overdischarge, sometimes provide load control functions.

◆ **Load**

- Energy consuming electrical appliances served by the system.

◆ **Balance of System (BOS) Components**

- Other equipment required to control, conduct, protect and distribute power in the system.

Photovoltaic Modules

◆ Module (690.2)

- A complete, environmentally protected unit consisting of solar cells, optics, and other components, exclusive of tracker, designed to generate dc power when exposed to sunlight.
- Range in size from around 0.5 to over 3 m² surface area, with peak power output of 50 to 300 watts dc. Area power densities range from 80-120 W/m².
- Most commercially available crystalline and multi-crystalline PV modules have 36 cells in series, and have open-circuit voltages of 20-22 volts dc, and can be connected in series up to 600 volts DC.
- Some thin-film modules have open circuit voltages as high as 100 volts dc.



**60-watt
poly-
crystalline
module**

**75-watt
crystalline
module**

Photovoltaic Arrays

◆ Array (690.2)

- A mechanical integrated assembly of modules or panels with a support structure and foundation, tracker, and other components, as required, to form a direct-current power-producing unit.



Inverters for PV Systems

◆ Inverter (690.2)

- Equipment that is used to change voltage level or waveform, or both, of electrical energy. Also known as a power processing unit (PCU) or power conversion system (PCS), and inverter is a device that changes dc input to ac output. Inverters may also function as battery chargers that use alternating current from another source and convert it into direct current for charging batteries.
- Inverters for PV systems in sizes from 100 watts to custom designs of up to 1 MW or more
- DC operating voltages of 12 volts up to 600 volts, with AC outputs from 120 V single phase to 480 V three phase.

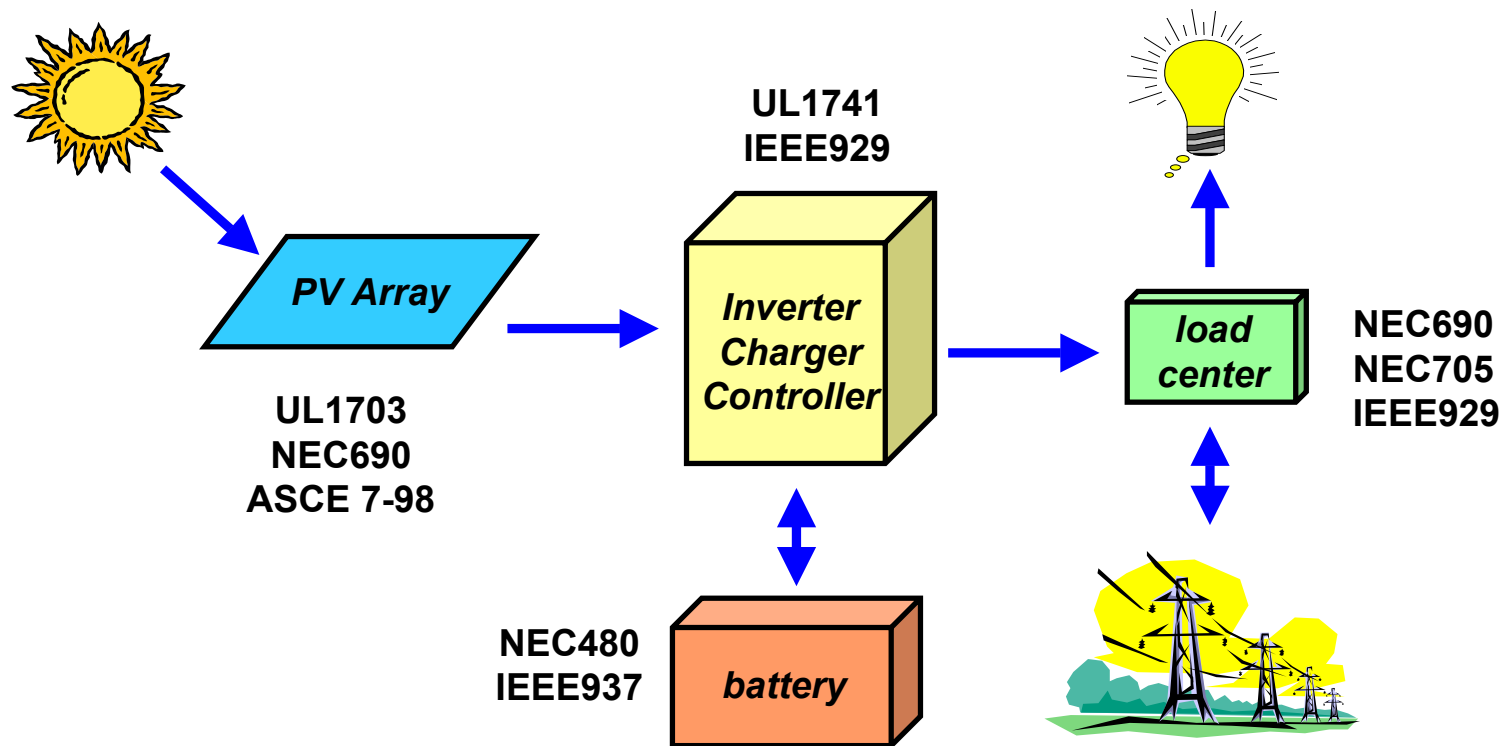


Batteries for PV Systems

- ◆ Batteries are used in some PV systems to *store energy* produced by the PV array and supply it to electrical loads as needed.
- ◆ Charge control is required in most cases to protect batteries from overcharge by PV array, and overdischarge from loads.



Solar Photovoltaic System: Applicable Codes by Component





Electrical Code Compliance and Equipment Listing

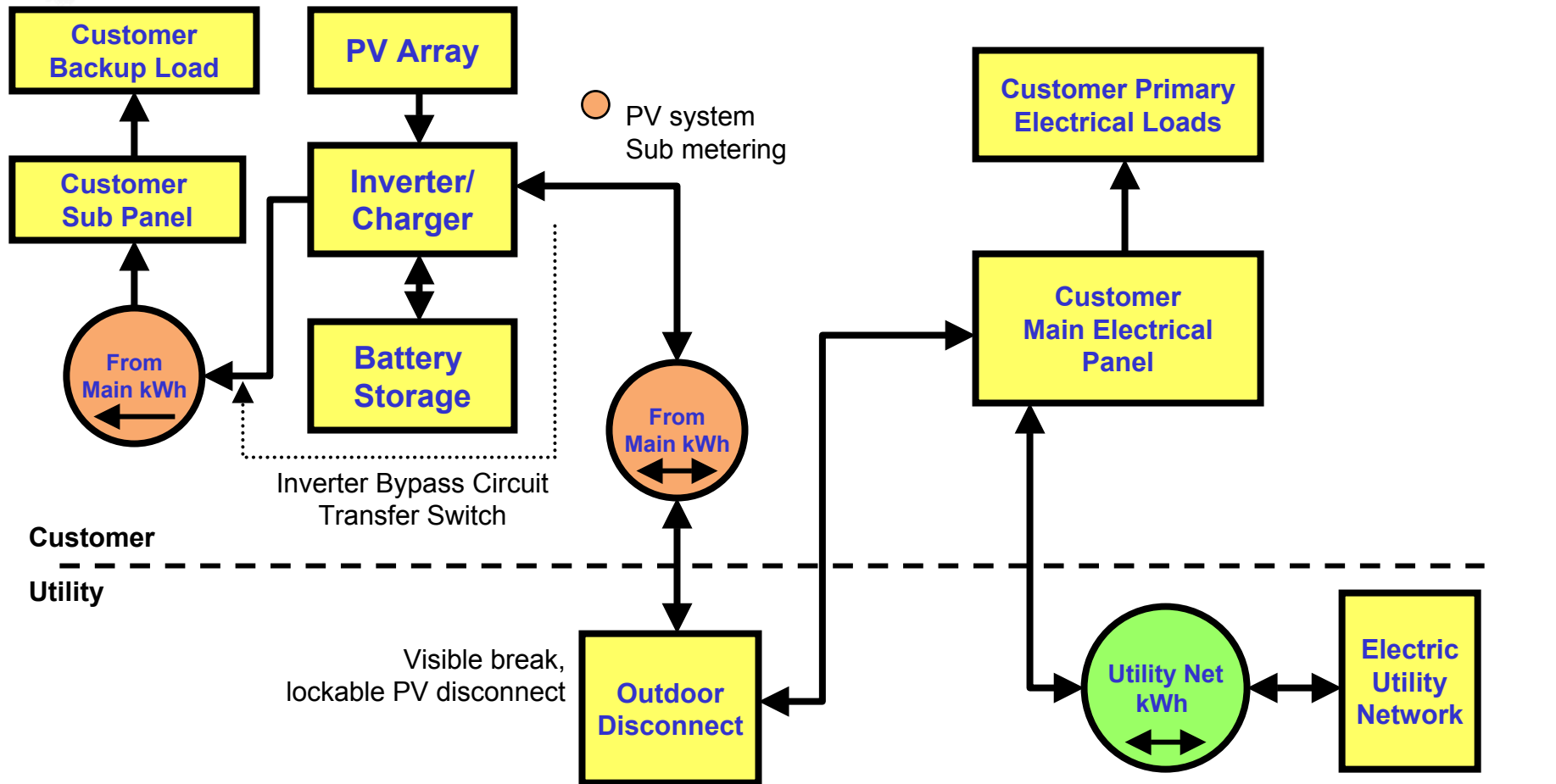
- ◆ NEC requires approvals or listing for components and electrical hardware. Recognized laboratories include:
 - Underwriters Laboratory (UL) <http://ulstandardsinfonet.ul.com>
 - ETL Semko <http://www.etlsemko.com>
 - Canadian Standards Association (CSA) <http://www.csa.ca>
 - FM Global <http://www.fmglobal.com>
- ◆ Article 110-3(B): Examination, Identification, Installation, & Use of Equipment.
 - **(B) Installation & Use.** Listed or labeled equipment shall be used or installed in accordance with any instructions included in the listing or labeling.



Utility Interconnection: Typical Issues

- ◆ Listed equipment
- ◆ Inspected and approved installations
- ◆ Liability insurance
- ◆ Disconnect provisions
- ◆ Metering options
- ◆ Billing practices
- ◆ Testing and monitoring
- ◆ Size restrictions
- ◆ Fees for interconnection application, special billing or metering

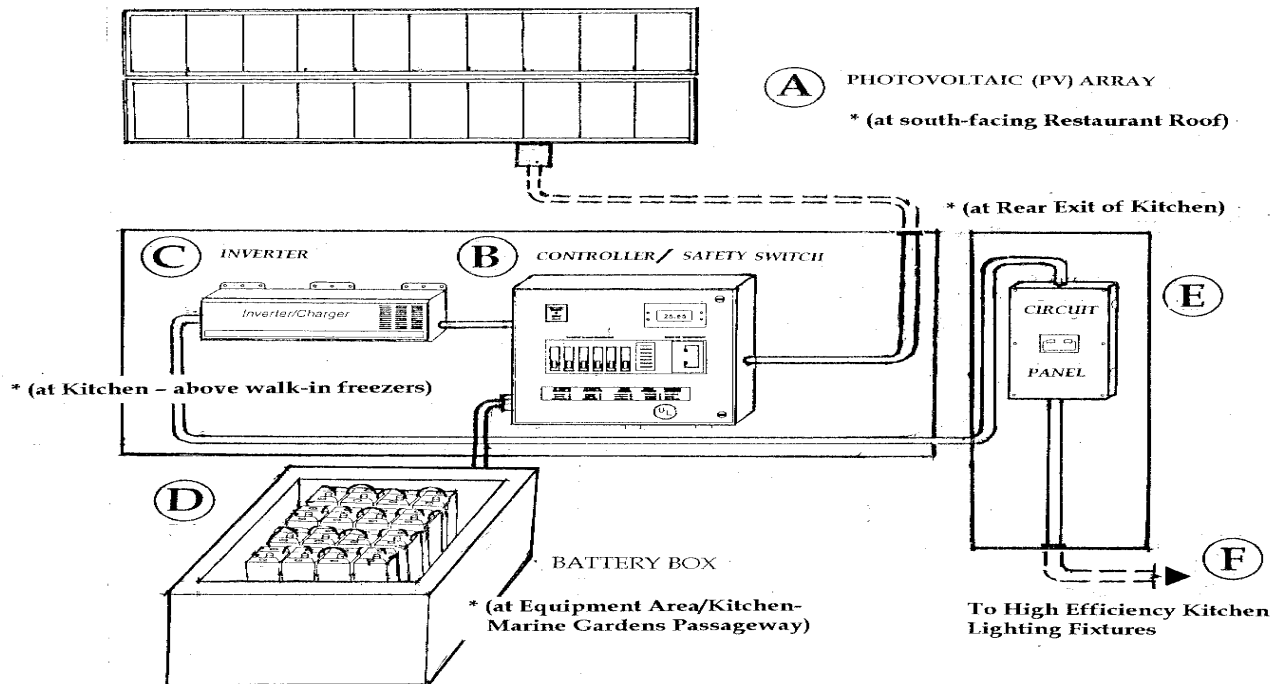
Utility-Interactive PV System with Battery Storage – Net Metering



* Arrows indicate directions of power flows

Standard, bi-directional revenue meter (utility-supplied)

Coral World PV System: One-line Design Diagram





Overcurrent Protection for PV Systems: Inspection Checklist

- ◆ Photovoltaic source circuit, photovoltaic output circuit, inverter output circuit and storage battery circuit conductors and equipment shall be protected in accordance with Art. 240 **[690.9(A)]**
- ◆ Overcurrent protection shall be provided for power transformers in accordance with Art. 450.3 **[690.9(B)]**
- ◆ Branch-circuit or supplementary-type overcurrent devices shall be provided for photovoltaic source circuits, no greater than series fuse on module listing **[690.9(C)]**
- ◆ Overcurrent devices are listed for use in dc circuits and shall have the appropriate voltage, current and interrupt ratings **[690.9(D)]**
- ◆ No issues with multiwire branch circuits **[690.10(C)]**



Batteries in PV Systems: Inspection Checklist

- ◆ Installation shall use appropriate racks, trays and ventilation [**480.8, 480.9, 480.10**]
- ◆ Operating voltage for dwelling less than 50 volts nominal - no more than 24 – 2-volt lead-acid cells in series [**690.71(B)**]
- ◆ Battery terminals and other live parts shall be guarded, adequate working space [**480.99(B),(C)**]
- ◆ Current-limiting fuses (types RK-5, RK-1, T) shall be installed on battery output circuits [**690.71(C)**]
- ◆ No conductive cases for batteries greater than 48 volts, nominal. Conductive racks permissible, must be at least 6” from top of battery case. [**690.71(D)**]
- ◆ Series disconnects shall be provided for battery strings over 48 volts, nominal [**690.71(E)**]
- ◆ Disconnect shall be provided for grounded conductor for battery systems over 48 volts, accessible only to qualified persons [**690.71(F)**]



Reference Resources

- ◆ Complete on-line resource for presentations, documents, reference and resource links:
 - <http://www.fsec.ucf.edu/PVT/Education/training/inspgcps/handbook/index.htm>
- ◆ Code and Standards for Photovoltaic Systems and Equipment:
 - <http://www.fsec.ucf.edu/PVT/RESOURCES/pvcodes/index.htm>
- ◆ Institute of Electrical and Electronics Engineers (IEEE) standards:
 - <http://standards.ieee.org/>
- ◆ Underwriters Laboratory standards:
 - <http://ulstandardsinfonet.ul.com/>
- ◆ National Electrical Code, NFPA 70, National Fire Protection Association:
 - <http://www.nfpa.org>



References (cont.)

- ◆ **Connecting to the Grid – Interstate Renewable Energy Association website:**
 - <http://www.irecusa.org/connect/index.html>
- ◆ **Florida Building Code**
 - <http://www.floridabuilding.org/>
- ◆ **ASCE 7-98 Minimum Design Loads for Buildings and Other Structures**
 - <http://www.asce.org/>

